Climate-Compatible Synthetic Liquid Fuels from Coal and Biomass with CO_2 Capture and Storage

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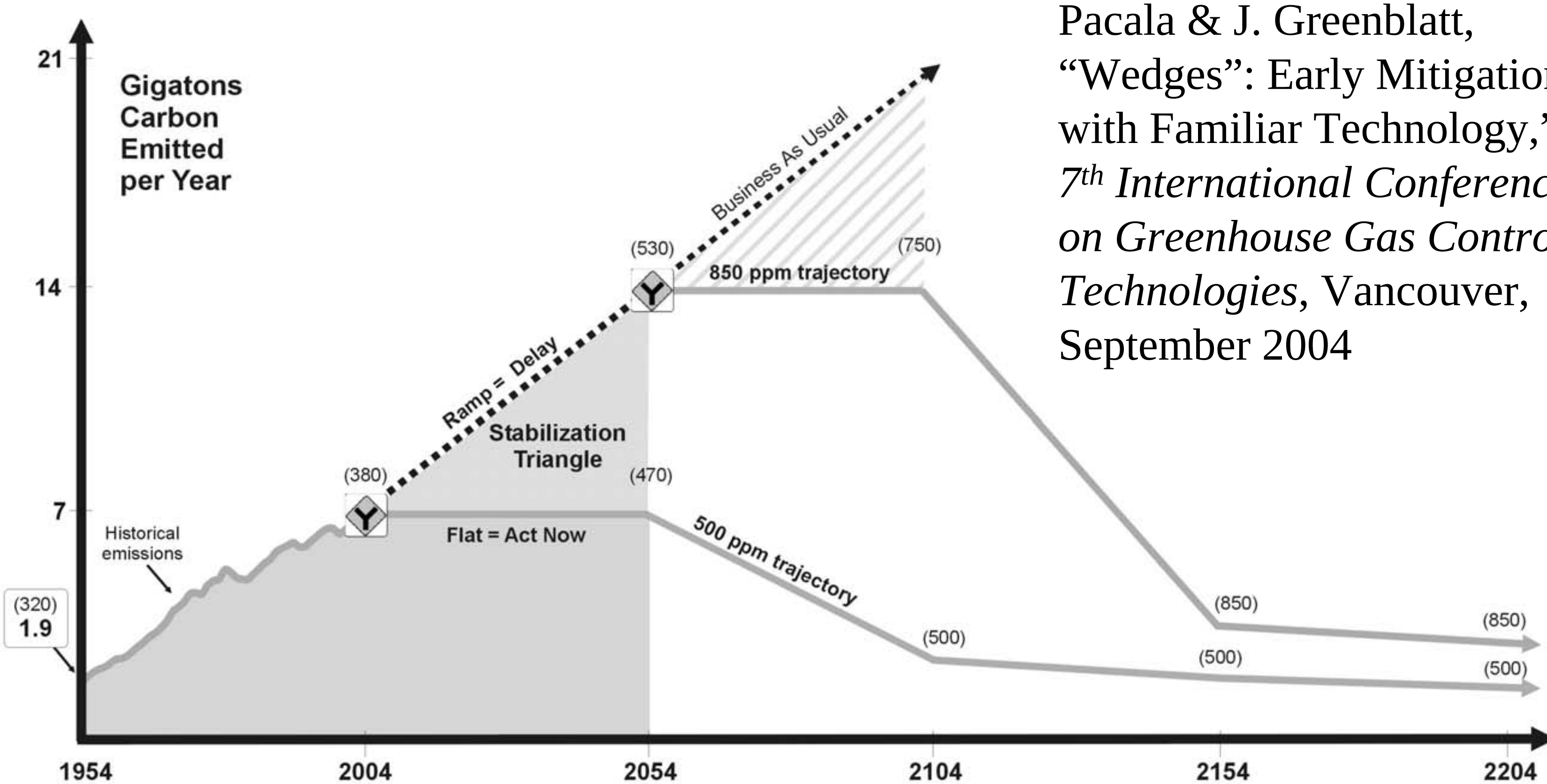
OUTLINE OF PRESENTATION

- Energy policy context
- Outlook for CO_2 capture and storage (CCS)
- Fischer-Tropsch liquids from coal with CO_2 vented and with CCS
- Fischer-Tropsch liquids from coal + biomass with CCS
- Getting started by selling CO_2 for enhanced oil recovery

TREND IN CLIMATE CHANGE MITIGATION POLICY

- Kyoto Protocol in force…implications of US exclusion
  - Replay of appliance efficiency standards fiasco (*appliance manufacturers' alarm in early 1980s about prospect of ~ 50 differing state standards implemented to compensate for federal inaction*)?
  - More costly climate mitigation "retrofits" needed later?
  - Replay of Betamax vs VHS?
- Carbon is being traded in EU @ $100/tC…price needed to induce CCS for least-costly coal power generation with aquifer storage of CO_2 (*CO_2-AqS*)
- Bipartisan Sense of Senate Resolution on Climate Change (*June 2005*) calling for mandatory constraints on CO_2 emissions
  - Passed 53-44
  - Overturned 1997 Byrd-Hagel Resolution
  - Supported by both prominent Republicans (*Domenici, Warner, Specter, McCain, Snowe, Collins*) and prominent Democrats (*Bingaman, Byrd, Lieberman*)

WHAT IS REQUIRED TO STABILIZE ATMOSPHERIC CO_2 AT $\leq$ 2X PRE-INDUSTRIAL LEVEL



Source: R. Socolow, S. Pacala & J. Greenblatt, "Wedges": Early Mitigation with Familiar Technology," *7th International Conference on Greenhouse Gas Control Technologies*, Vancouver, September 2004

Cumulative CO_2 emissions < 600 GtC during 2004-2104
+ 200 GtC during 2104-2204 for 500 ppmv trajectory

OIL AND COAL CONTRIBUTIONS TO GLOBAL CO_2 EMISSIONS (2002) ARE COMPARABLE:

	2002, according to IEA (WEO)	
	Energy, EJ (%)	CO_2 emissions, GtC (%)
Coal	100.3 (23.1)	2.46 (38.3)
Oil	154.4 (35.5)	2.63 (40.9)
Oil in transportation	73.0 (16.8)	1.30 (20.2)
Coal power	68.9 (15.9)	1.81 (28.1)
Total	434.5 (100)	6.43 (100)

For gasoline and Diesel used in transportation, fuel-cycle-wide GHG emissions are 1.30 and 1.25 times the direct CO_2 emissions, respectively

➔ GHG emissions are also comparable for oil in transportation and coal power

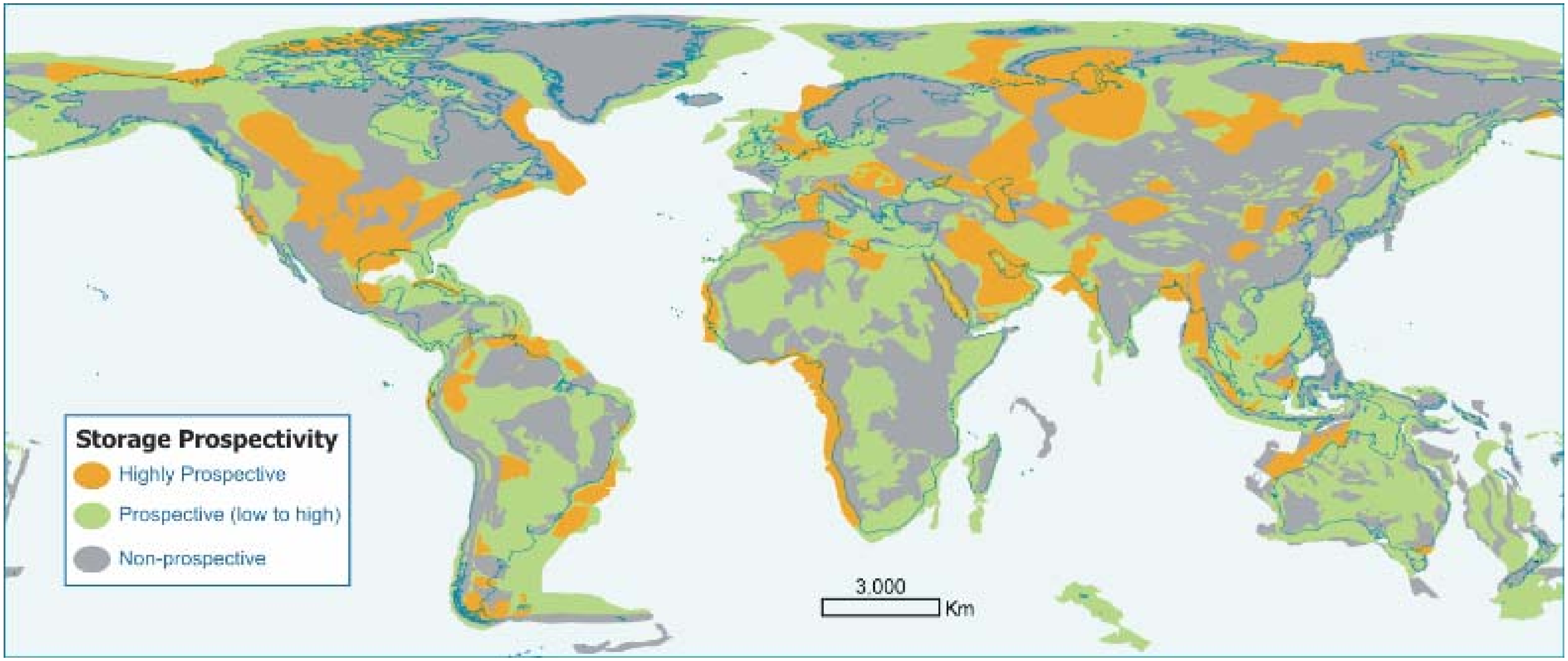
OUTLOOK: LIQUID TRANSPORTATION FUELS

- Outlook for oil:
  - Peaking of non-OPEC conventional oil production ~ 2010-2015
  - Likelihood that OPEC (*mainly ME producers*) will be unwilling (*unable*) to fully bridge rapidly expanding world oil demand/non-OPEC production gap
  - Supply security concerns about growth in ME share of world oil production
  - Prices (2004$), EIA *AEO 2006* Reference Scenario: **\$47/bbl (2010) → \$57/bbl (2030)**
- Coal liquids will play dominant role among non-conventional oil sources:
  - Huge reserves; low and stable coal prices;
  - Commercially ready technologies to make super-clean "designer" synfuels.
- Coal synfuel GHG emissions >> than for oil-derived HC fuels…but:
  - CO_2 capture and storage (CCS) can reduce GHG emission rates to levels for oil
- Coprocessing coal + biomass to make synfuels with CCS for both:
  - Exploit scale economies of coal energy systems;
  - Exploit negative CO_2 emissions potential for bioenergy with CCS;
  - Reduce net GHG emissions for liquid transport fuels to near zero;
  - Provide liquid fuels in widespread applications with near-commercial technologies at prices that are competitive with crude oil ~ \$45/barrel and GHG emissions valued at \$100/tC_{equiv}
  - More than 2X as much low GHG-emitting liquid fuel production and total GHG emissions avoided per EJ of biomass than with conventional biofuels;

OPTIONS FOR CO_2 STORAGE

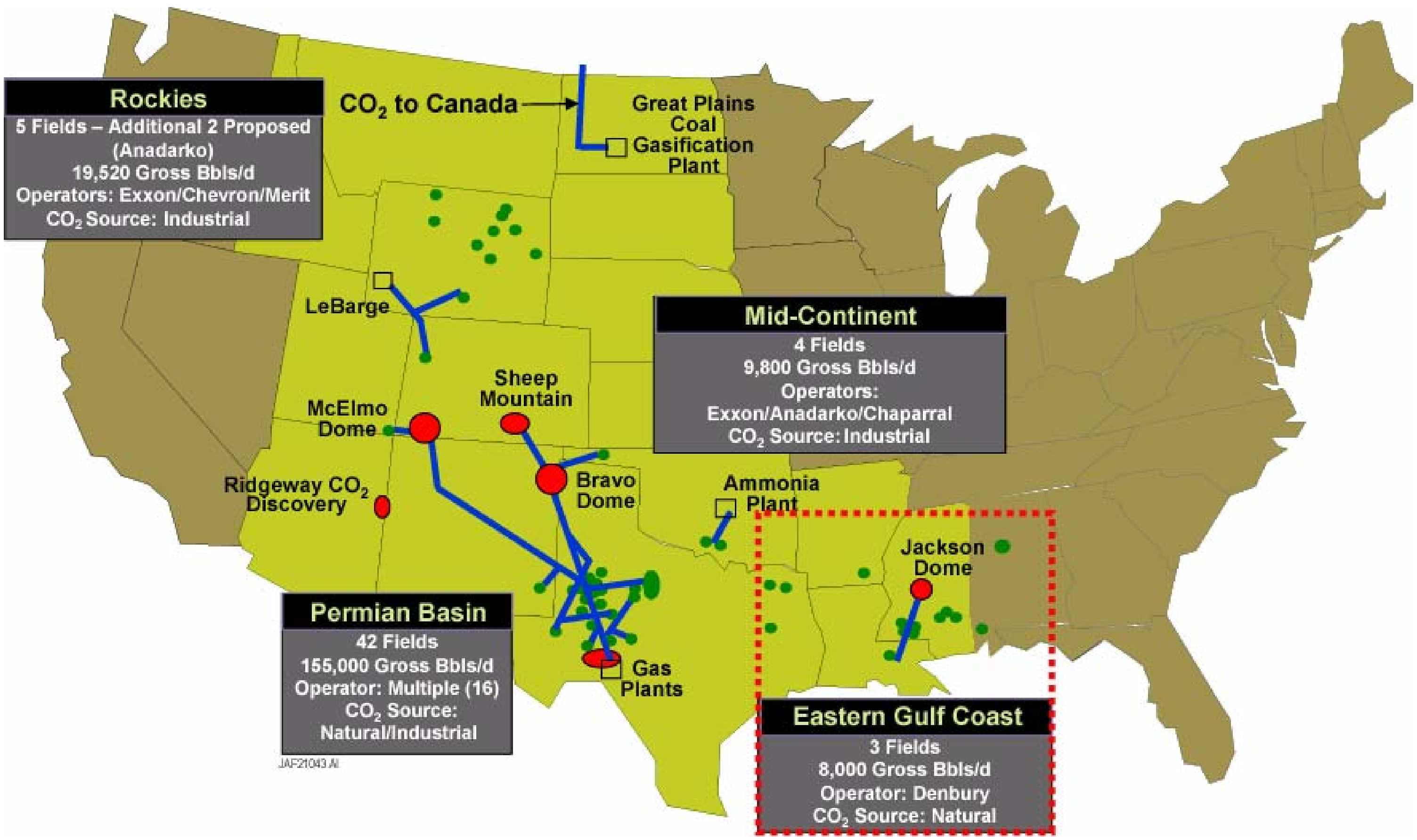
- Goal: store 100s to 1000s of Gt CO_2 for 100s to 1000s of years
- Major options, disposal in:
  - Deep ocean (*concerns about storage effectiveness, environmental impacts, legal issues, difficult access*)
  - Carbonate rocks [*100% safe, costly (huge rock volumes), embryonic*]
  - Disposal in geological media (*focus of current interest*)
    - Enhanced oil recovery (*30 million tonnes CO_2/y—4% of US oil production*)
    - Depleted oil and gas fields (*geographically limited*)
    - Beds of unminable coal (*CO_2 adsorbed in pore spaces of coal*)
    - Deep saline aquifers—huge potential, ubiquitous (*at least 800 m down*)
      - Such aquifers underly land area = ½ area of inhabited continents (*2/3 onshore, 1/3 offshore*)
  - Most large anthropogenic CO_2 sources within 0-200 km of geological disposal sites (*800 km = longest US CO_2 pipeline for EOR*)
  - Already some experience (*e.g., Sleipner, North Sea; In Salah, Algeria*)

STORAGE POTENTIAL FOR CO_2 IN SEDIMENTARY BASINS OF THE WORLD



Source: J. Bradshaw and T. Dance, 2004: Mapping geological storage prospectivity of CO_2 for the world's sedimentary basins and regional source to sink matching. *Proceedings of the 7th International Conference on Greenhouse Gas Technologies*, September 5-9, 2004, Vancouver, Canada.

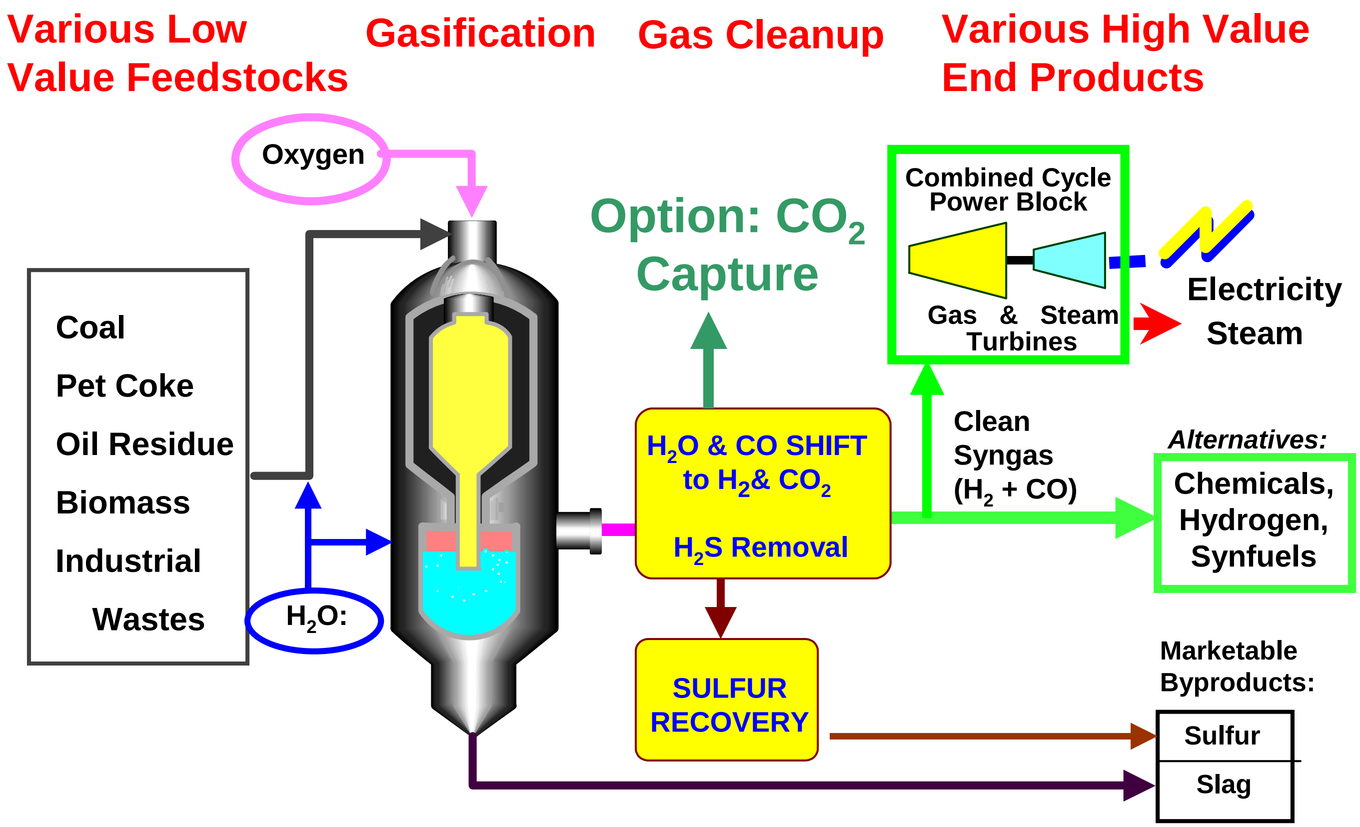
EXTENSIVE US EXPERIENCE WITH CO_2 TRANSPORT FOR ENHANCED OIL RECOVERY …SOME CO_2 IS ANTHROPOGENIC



MAIN MESSAGES—IPCC SPECIAL REPORT ON CCS

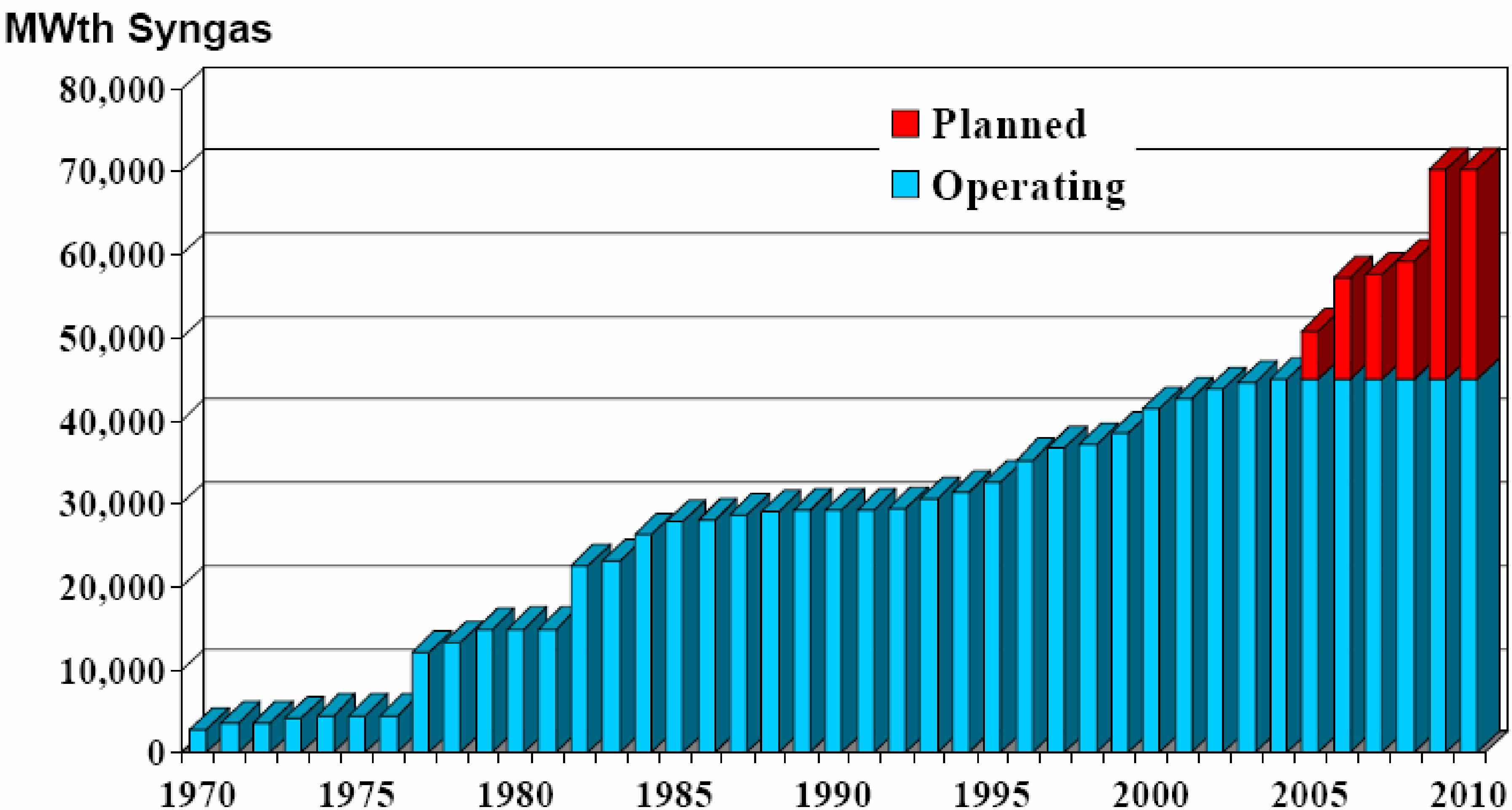
- IPCC is:
  - positive on geological storage,
  - not so positive on ocean storage or mineralization
- CO_2 capture and storage (*CCS*) can:
  - contribute 15% to 55% in mitigating climate change
  - reduce climate mitigation cost 30% or more
  - reduce emissions 80-90% compared to plant w/o CCS
- CCS plants require 10-40% more energy than plants w/o CCS
- 66-90% probability that worldwide geo-storage capacity at least 2000 Gt CO_2 (*fossil fuel emissions = 24 Gt CO_2 in 2002*)
- Geological storage, fraction retained:
  - 90-99% probability that retained fraction will exceed 99% over 100 y
  - 66-90% probability that retained fraction will exceed 99% over 1000 y
- CO_2 pipeline risk ~ to or < than for HC pipelines in operation

GASIFICATION TO CONVERT LOW-VALUE FEEDSTOCKS INTO HIGH-VALUE PRODUCTS



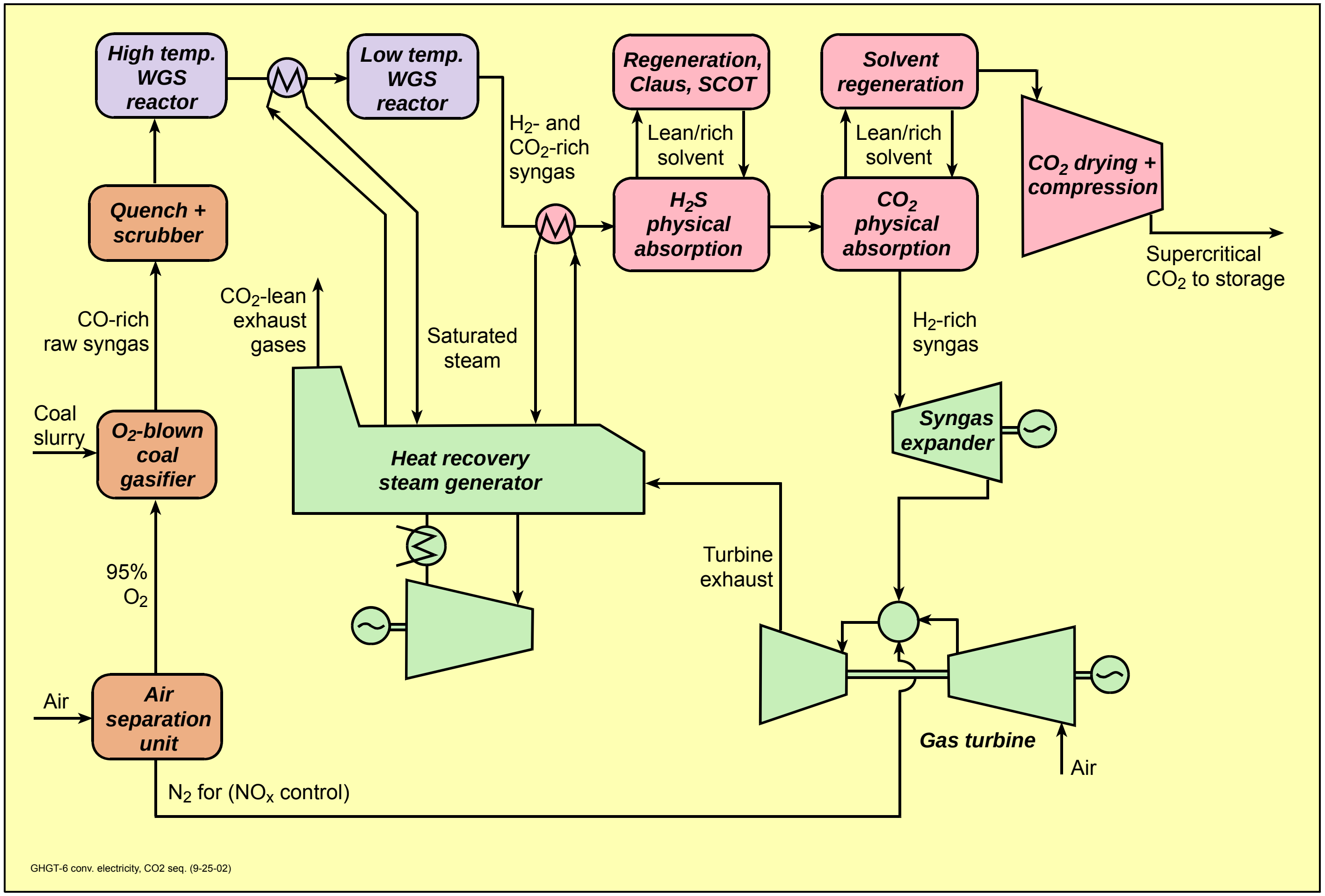
Gasification in O_2/steam of coal, biomass, other carbonaceous materials: key enabling technology for making clean energy (*liquid fuels and electricity*) and for low-cost CO_2 capture & storage (*CCS*)

Cumulative Worldwide Gasification Capacity and Growth



Childress Gasification Database 11/2004

COAL IGCC WITH CO_2 CAPTURE (C-IGCC-C)



With CO_2 storage in aquifer (*CO_2-AqS*) 100 km from plant:
Generation cost = 6.6 ¢/kWh vs 4.7¢ /kWh with CO_2 vented (*C-IGCC-V*).
Shift requires GHG emissions value ~ \$100/tC_{equiv} (*\$27/tCO2$_{equiv}$*)

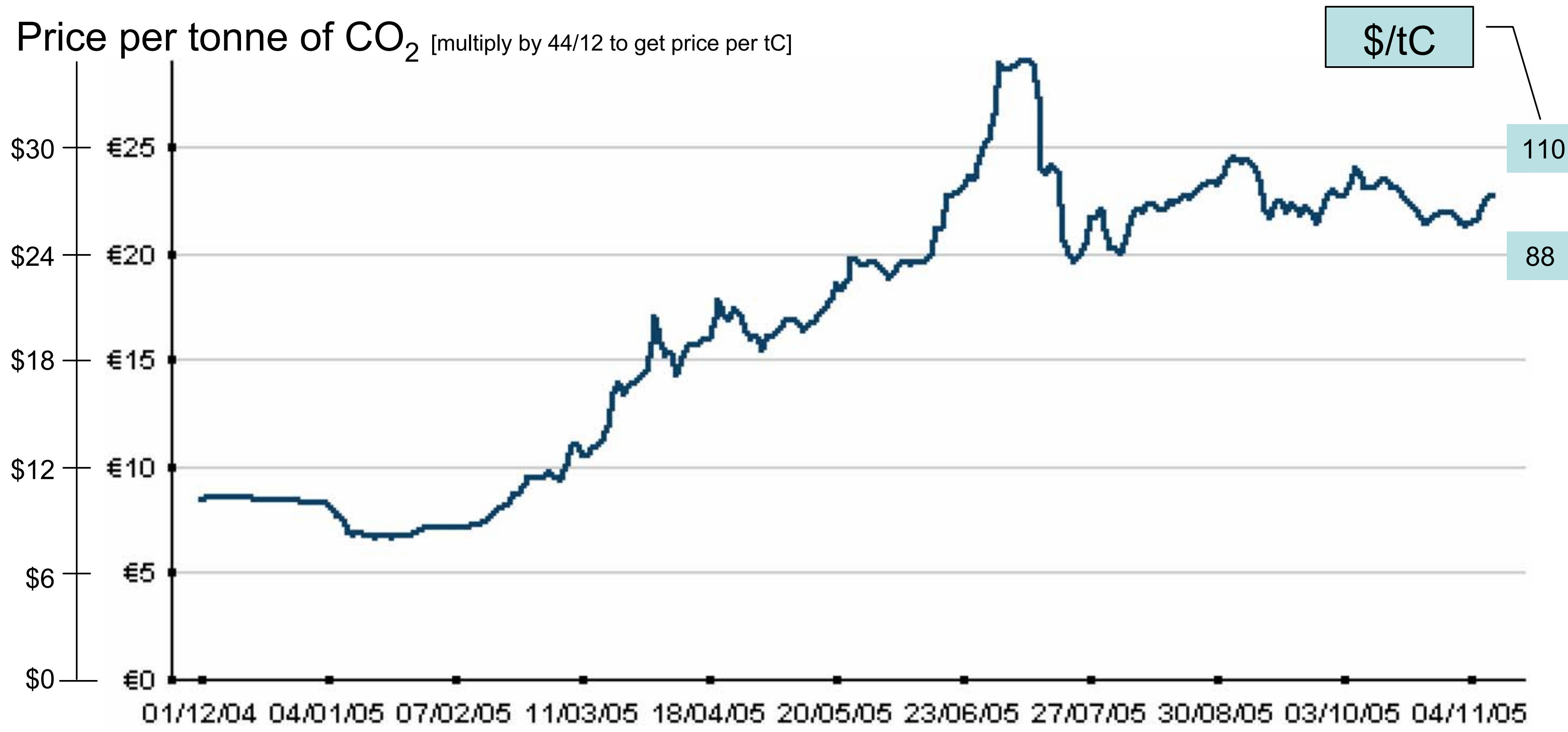
\$100/t C (\$27/t CO_2)

Carbon emission charges ~ \$100/tC would enable
CCS for coal gasification-based energy systems

Form of Energy	**Equivalent to \$100 per tC**
Natural gas	\$1.5/Mscf (*2004 US wellhead price = \$5.5/Mscf*)
Crude oil	\$12/bbl (*2004 US refiner acquisition cost = \$37/bbl*)
Coal	\$65/st (*2004 coal price for electric utilities = \$27/st*)
Gasoline	25¢/gallon (*EthOH subsidy: 76¢/gallon gasoline equivalent*)
Average electricity from coal	2.7 ¢/kWh
Electricity from NGCC	1.1¢/kWh
Today's global energy system	\$660 billion/year (*1.4% of GWP*)

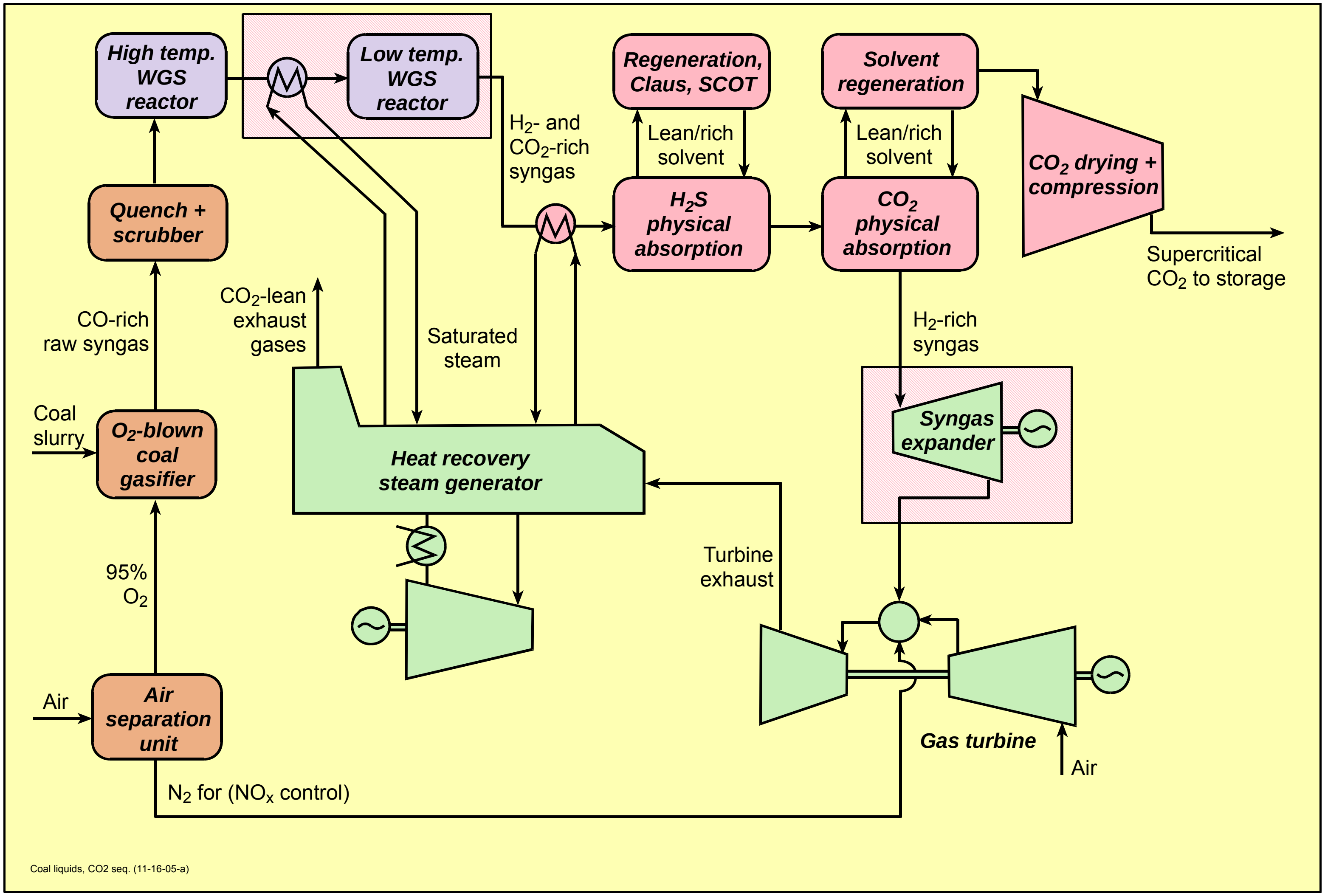
\$100/tC is approximately the October 2005 EU trading price.

European Trading Scheme (ETS) Carbon Market Price History



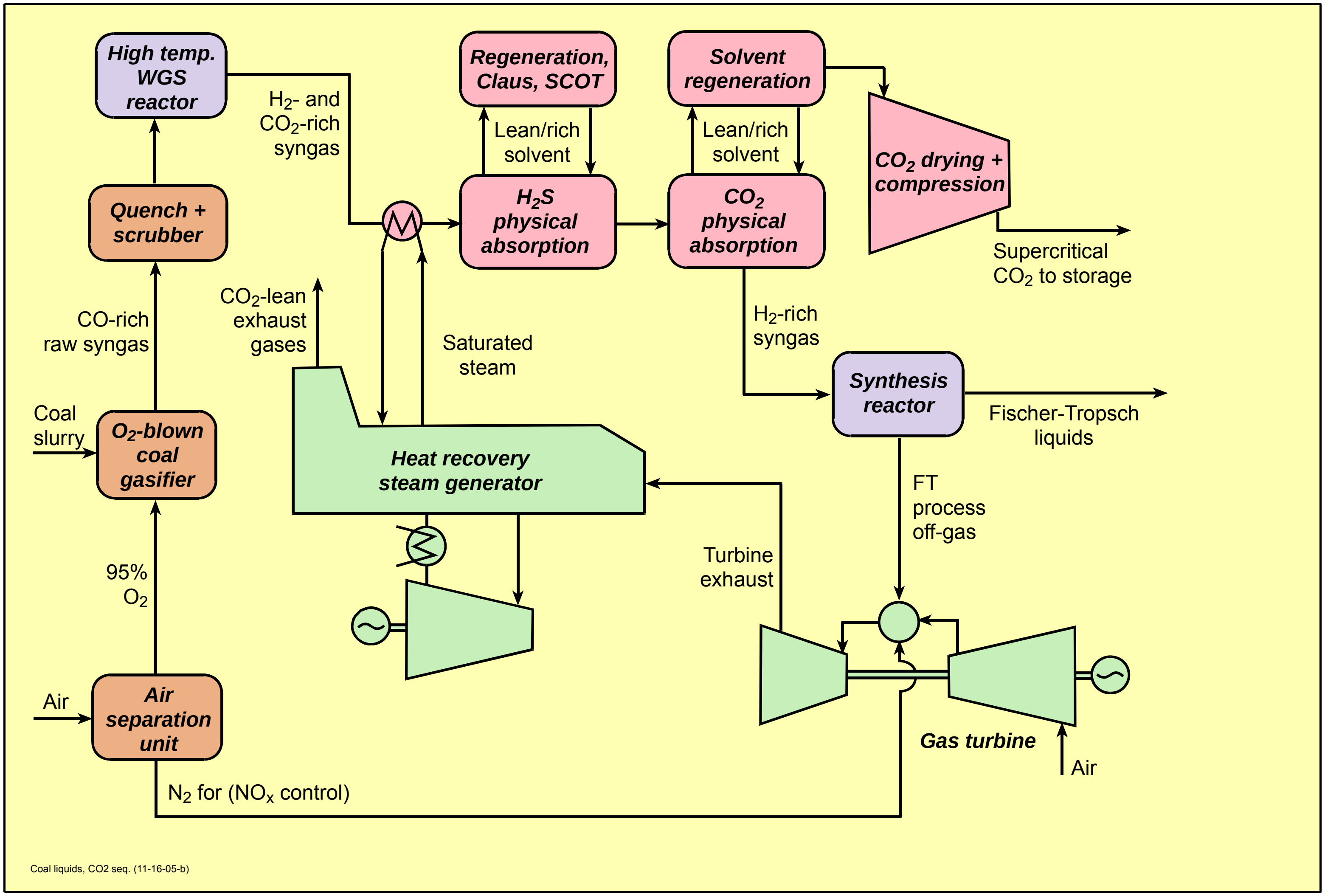
Source: www.pointcarbon.com (accessed 11/11/05). These are Point Carbon's estimated daily average bid-offer closing prices (as of 16:30 London time each business day) based on actual over-the-counter brokered prices at carbon exchanges operating under the ETS. (Conversion from Euro to US$ based on exchange rate prevailing 10/26/05.)

CONVERTING C-IGCC-C PLANT TO TO C-FT-C PLANT



Get rid of low-temperature water gas shift reactor and syngas expander

FTL PRODUCTION



With liquid phase synthesis reactors ➔ FTL cost is lower if syngas passed only once through synthesis reactor…making electricity coproduct by burning unconverted syngas

CATALYTIC SYNTHESIS OF FUELS FROM SYNGAS

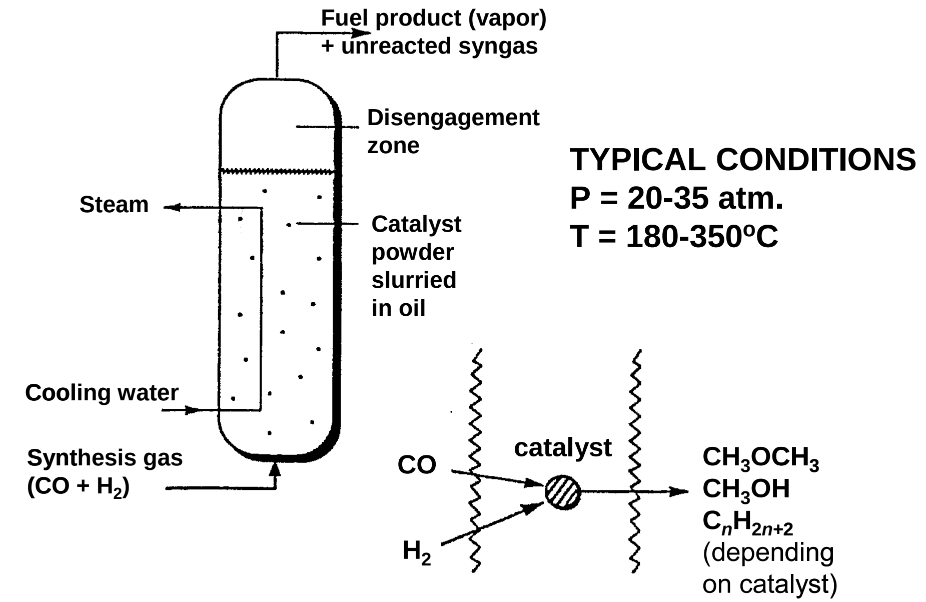
- **Basic overall reactions**:

$$CO + 2H_2 \Leftrightarrow -CH_2- + H_2O$$ Fischer-Tropsch liquids (FTL)

$$3CO + 3H_2 \Leftrightarrow CH_3OCH_3 + CO_2$$ Dimethyl ether (DME)

$$CO + 2H_2 \Leftrightarrow CH_3OH$$ Methanol (MeOH)

- **Three reactor designs**:
  - Fixed-bed (*gas phase*): low one-pass conversion, difficult heat removal
  - Fluidized-bed (*gas phase*): better conversion, more complex operation
  - Slurry-bed [*liquid phase* (*LP*)]: much higher single-pass conversion (*e.g., for FTL, 80% with LP vs. 40% with gas phase*)
    - LP-FTL reactors are commercial
    - LP-MeOH commercially demonstrated
    - LP-DME near commercial
  - Focus here on
    - LP synthesis
    - FTL



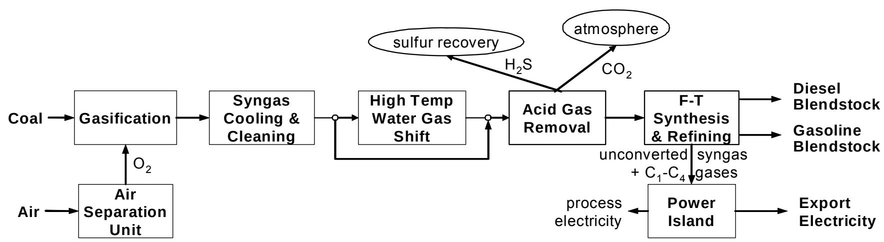
Liquid Phase Reactor

Fischer-Tropsch fuels (straight-chain C_nH_{2n} , C_nH_{2n+2})

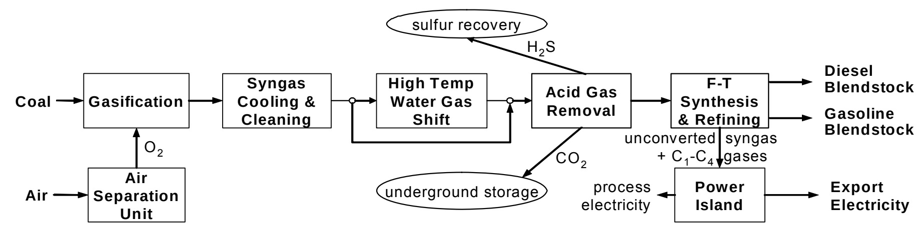
- FTLs of interest include high-cetane, low-aromatic, no-sulfur diesel substitute and naphtha as chemical feedstock upgradable to gasoline blendstock.
- FTL technology is commercially established
- Coal FTL projects:
  - Sasol II & III in South Africa, 150k barrelsl/day (bpd) total capacity
  - 20k bpd, Inner Mongolia (2007)
  - 2 x 80k bpd, Sasol/China feasibility study
  - 5k bpd demo, Gilberton, Pa (2008)
  - 33k bpd and 57 bpd projects proposed in Wyoming
- Stranded natural gas FTL projects:
  - From 1990s in Malaysia: 13k bpd
  - Planned:
    - Qatar, 2005: 34k bpd
    - Nigeria, 2006: 34k bpd
    - Qatar, 2009 (140k bpd) and 2011 (154k bpd)

ALTERNATIVE FT POLYGENERATION CONFIGURATIONS

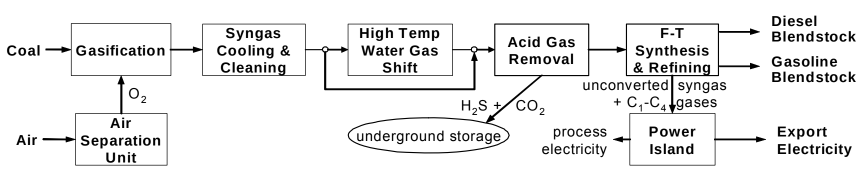
C-FT-V



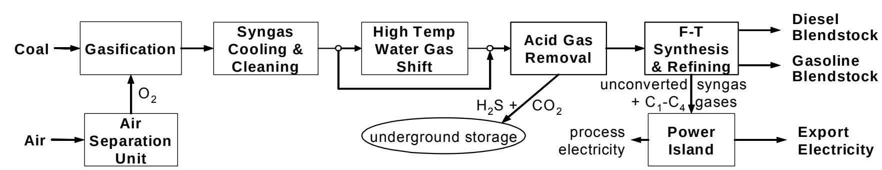
C-FT-C



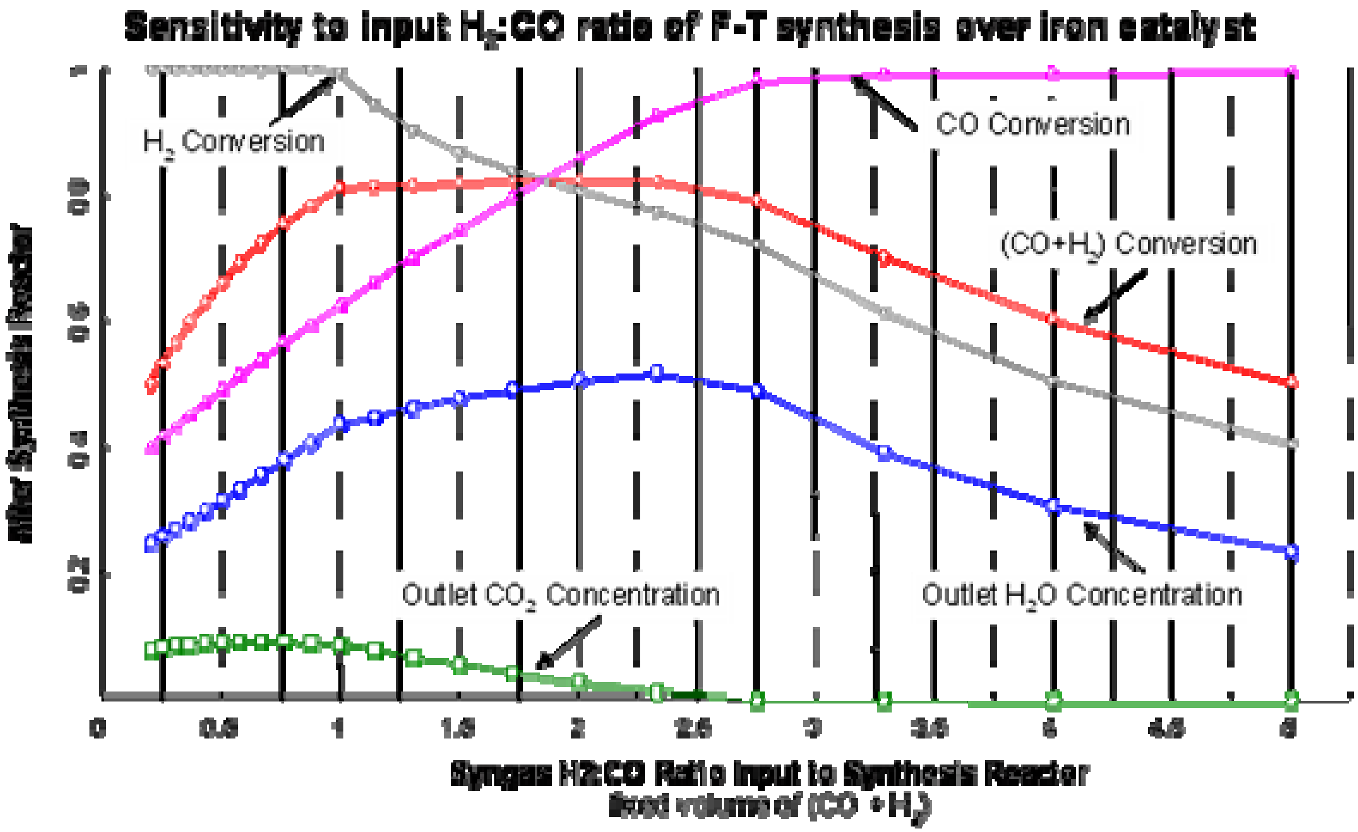
C-FT-CoC



C/B-FT-CoC



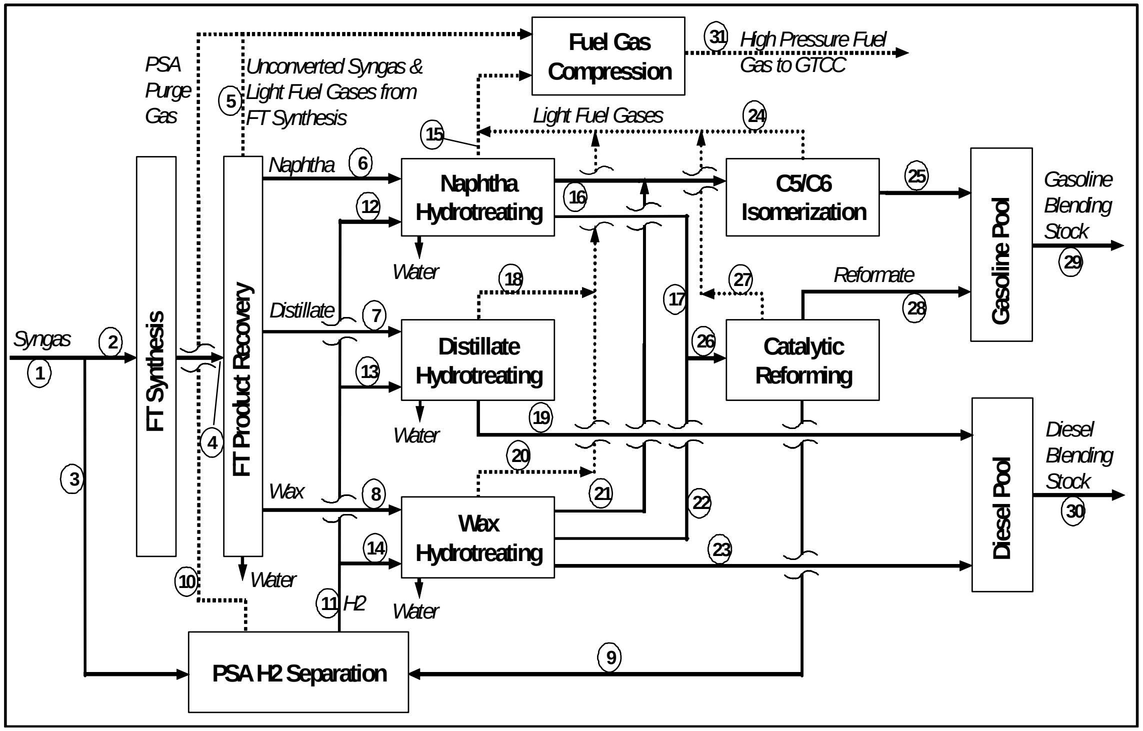
DESIRED H_2:CO RATIO FOR FTL WITH CCS?



H_2:CO = 2.75 is chosen, because at this ratio: (*i*) FTL yield is near maximum (*maximum at H_2:CO = 2.25, value assumed for vent case*), (*ii*) CO_2 level is essentially zero, and (*iii*) CO conversion is almost complete…but there are still minor CO_2 emissions from power plant

SOURCES OF COAL-DERIVED CO_2 EMISSIONS FOR ELECTRICITY FROM POLYGENERATION UNIT?

	HHV, MW	LHV, MW	Carbon flow, kgC/s
1	2622.0	2327.6	29.85
2	2597.7	2306.1	29.57
3	24.2	21.5	0.28
4	2246.6	1957.2	18.51
5	914.4	804.5	6.96
6	245.8	228.9	4.47
7	129.5	120.7	2.34
8	859.6	803.1	4.79
9	51.7	44.7	0.22
10	29.0	26.5	0.52
11	46.9	39.7	0.00
12	8.5	7.2	0.00
13	3.1	2.6	0.00
14	35.3	29.9	0.00
15	14.8	13.6	0.25
16	24.1	22.4	0.43
17	209.7	194.7	3.70
18	1.2	1.1	0.02
19	127.8	118.9	2.29
20	46.6	43.1	0.78
21	94.3	87.5	1.66
22	167.6	155.6	2.92
23	575.8	535.4	10.27
24	2.2	2.1	0.04
25	116.2	107.9	2.05
26	377.4	350.2	6.66
27	28.6	26.4	0.48
28	324.1	300.8	5.72
29	430.7	391.9	7.77
30	682.9	639.8	12.62
31	1036.9	917.4	9.01

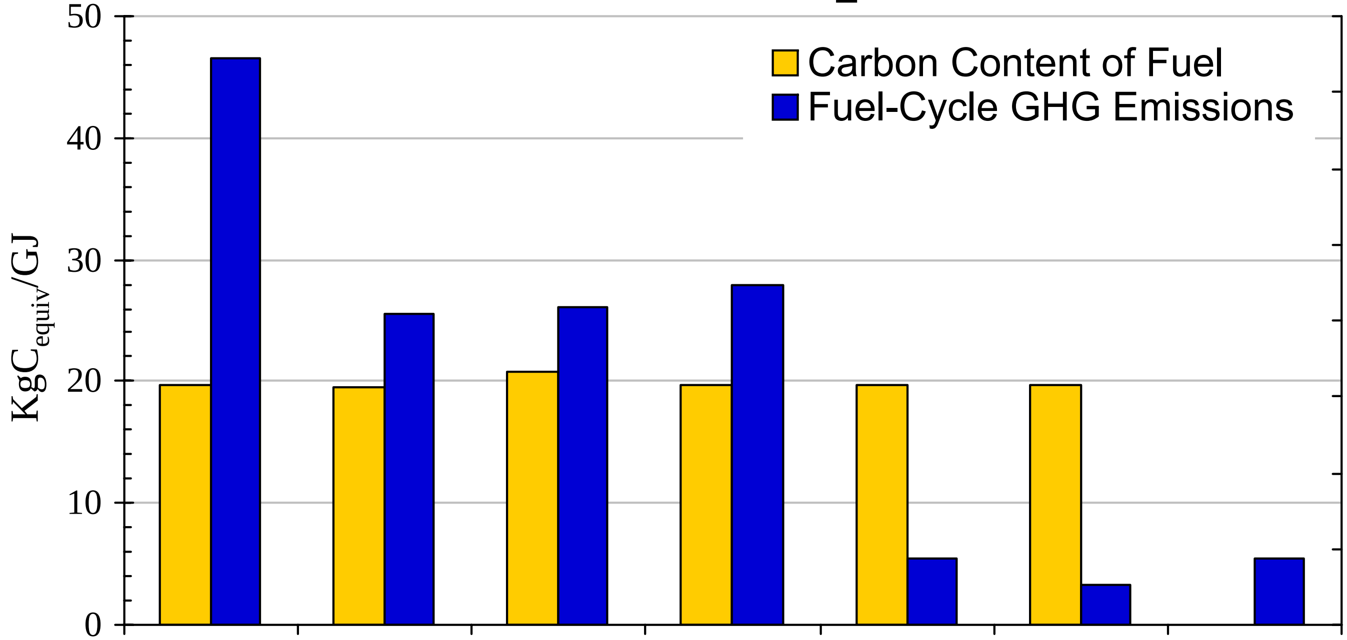


Gas turbine is fired with:

- syngas unconverted in single pass through synthesis reactor (*mostly H_2*)
- light gaseous byproducts (*C1-C4*) from raw FTL refinery

← **Energy/carbon flows for C/B-FT-CoC case**

GHG EMISSIONS FOR ALTERNATIVE FTL OPTIONS + COMPARISONS TO CRUDE-OIL PRODUCTS & COAL H_2 WITH CCS



Energy Carrier	FTL	Gasoline	Diesel	FTL	FTL	FTL	Hydrogen
Primary Energy Source	Coal	Crude Oil	Crude Oil	Coal	**Coal/Biomass**	Biomass	Coal
CO_2 Capture and Storage?	No	No	No	Yes	Yes	No	Yes

Emission rate for C-FT-V ~ 1.8 X that for crude oil-derived fuels but emission rates comparable for C-FT-C and crude oil-derived fuels

E/C BALANCES FOR MAKING FTL + ELECTRICITY FROM COAL WITH CCS

8.0 kgC vented as
Coal-derived CO_2

20.3 kgC
released in
FTL combustion

2.99 GJ **Coal**
75.3 kgC

Making FTL + Electricity
via C-FT-C

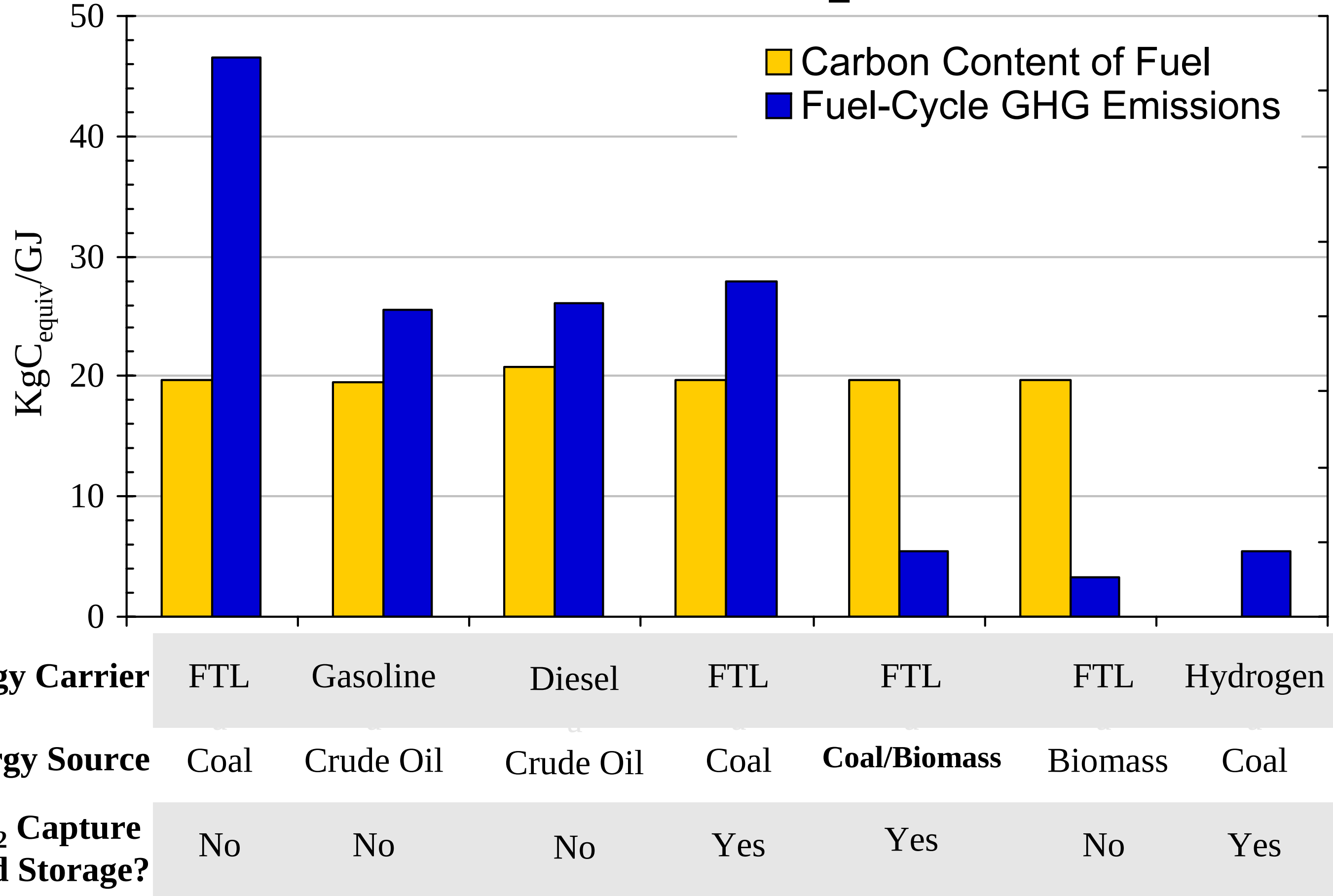
1.0 GJ FTL +
0.38 GJ electricity

46.2 kgC as CO_2 from coal stored
underground + **0.8 kgC** in char

C balance for coal: **75.3 – 8.0 - 20.3 – 46.2 – 0.8 = 0 kgC per GJ FTL**

Direct net CO_2 emissions: 8.0 + 20.3 = 28.3 kgC per GJ FTL

GHG EMISSIONS FOR ALTERNATIVE FTL OPTIONS + COMPARISONS TO CRUDE-OIL PRODUCTS & COAL H_2 WITH CCS



GHG emission rate for C/B-FT-CoC chosen to = rate for coal H_2 with CCS (5.5 kgC_{equiv}/GJ)…this determines relative coal/biomass inputs

E/C BALANCES FOR MAKING FTL + ELECTRICITY FROM COAL + BIOMASS WITH CCS

6.4 kgC vented as
Coal-derived CO_2

20.3 kgC
released in
FTL combustion

Biomass
0.86 GJ (28%)
Coal
2.17 GJ (72%)
54.7 kgC

Making FTL + Electricity
via C/B-FT-CoC

1.0 GJ FTL +
0.45 GJ electricity

21.6 kgC as CO_2 from biomass stored underground (91*% of C in biomass*)

27.4 kgC as CO_2 from coal stored underground + **0.6 kgC** in char

C balance for coal: **54.7 - 6.4 - 20.3 – 27.4 – 0.6 = 0 kgC per GJ FTL**
Direct net CO_2 emissions: 6.4 + 20.3 – 21.6 = 5.1 kgC per GJ FTL

FUEL-CYCLE-WIDE GHG EMISSION RATE FOR FTL FROM COAL + BIOMASS WITH CCS

(kgC_{equiv}/GJ *of FTL*)

Direct net CO_2 emissions from conversion plant and FTL burning	5.1
Upstream from coal @ 1 kgC_{equiv}/GJ coal (*GREET model, US*)	+ 2.2
Upstream from biomass @ 2.1 kgC_{equiv}/GJ switchgrass (*GREET model, US*)	+ 1.8
Allocated to electricity @ 29 gC_{equiv}/kWh (*rate for coal IGCC with CCS*)	- 3.6
Net GHG emissions allocated to FTL	5.5

FUEL-CYCLE-WIDE GHG EMISSION RATE FOR CRUDE-OIL-DERIVED HC FUELS

(kgC_{equiv}/GJ *of Liquid Fuel*)

Net GHG emissions for gasoline (*GREET model, US*)	25.6
Net GHG emissions for diesel (*GREET model, US*)	26.1

COMPARING LOW-C LIQUID FUEL YIELDS PER GJ OF BIOMASS FEEDSTOCK

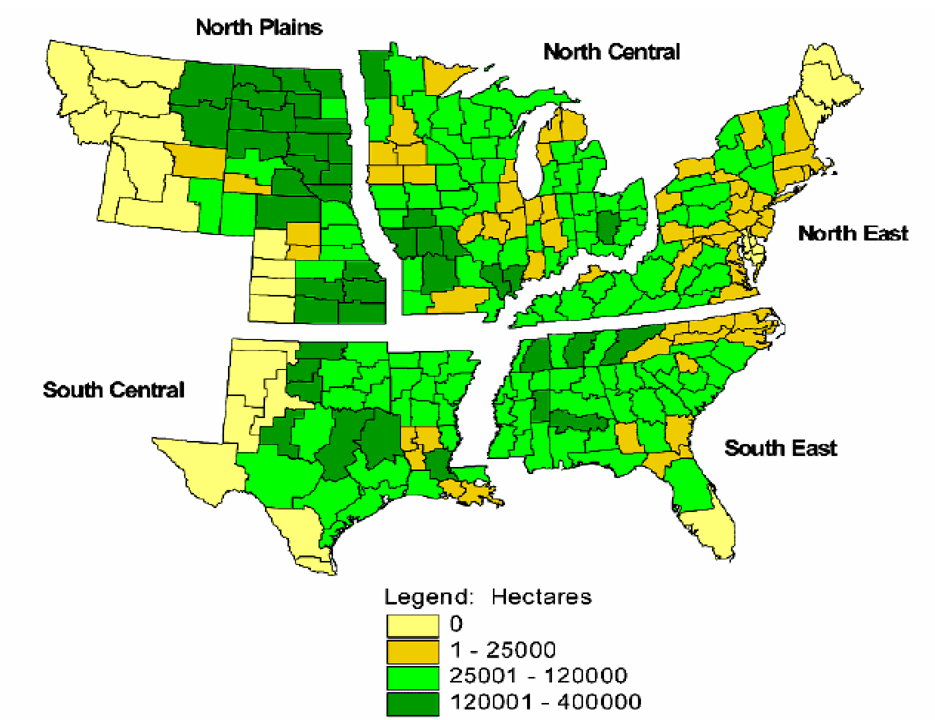
FTL from coal + biomass with CCS	1.16 GJ
Cellulosic Ethanol from biomass[a]	
Current technology (*255 liters/dry tonne*)	0.37 GJ
Future technology (*340 liters/dry tonne*)	0.49 GJ

[a] Source: J. Sheehan, A. Aden, K. Paustian, K. Killian, J. Brenner, M. Walsh, and R. Nelson, "Energy and environmental aspects of using corn stover for fuel ethanol, *Journal of Industrial Ecology*, **7** (3-4): 117-146, 2004.

Biomass/coal FTL with CCS offers 2.4 to 3.2 X as much low GHG-emitting liquid fuel from biomass compared to cellulosic EthOH

BIOMASS FEEDSTOCK OPTIONS

- Agricultural/forest product industry residues in near term
  - Forest product industry residues (*2.3 Quads/y at present in US*)
  - Crop residues (*3.1 Quad/y at present in US*)
- Energy crops—e.g., switchgrass in Great Plains—for longer-term



Source: McLaughlin et al., 2002: High-value renewable energy from prairie grasses, *Envir. Sci.& Tech.*, **36** (10): 2122-2129

Using POLYSIS (an agricultural model) this study projected that if market will accept switchgrass at current average delivered cost (\$54/t or \$3.0/GJ_{HHV}), 17 x 10^6 ha in US would be converted to switchgrass @ 9.4 t/ha/y average yield, producing 2.8 Quads/y

Even at current high biomass prices *(~ 2.5 X coal price for power*) **bioenergy with CCS can be cost-effective under climate constraint**

THOUGHT EXPERIMENT #1 FOR US

- Use 100% of current US crop/forest residues in C/B-FT-CoC systems
- Increase average LDV fuel economy 2.4 X (*to 48 mpg*)
- Implications:
  - Can support 100% of US light duty vehicles (*203 million in 2002*)
  - decarbonized coproduct coal electricity ≡ 40% of US coal electricity in 2002
  - Net coal consumption up 6.0 Quads/year (*up 27.5%*)
  - CO_2 storage rate = 1.1 x 10^9 tonnes CO_2/y (*19% of US CO_2 emissions in 2002*)
  - 238 C/B-FT-CoC plants required (*each producing 14,000 B/D gasoline equivalent of low-C FTL + 459 MW_e of low-C electricity*) costing $1.9 billion per plant

CO_2 ENHANCED OIL RECOVERY (EOR): OPPORTUNITY FOR LAUNCHING CCS ACTIVITIES WITH LOW/ZERO VALUATION OF GHG EMISSIONS

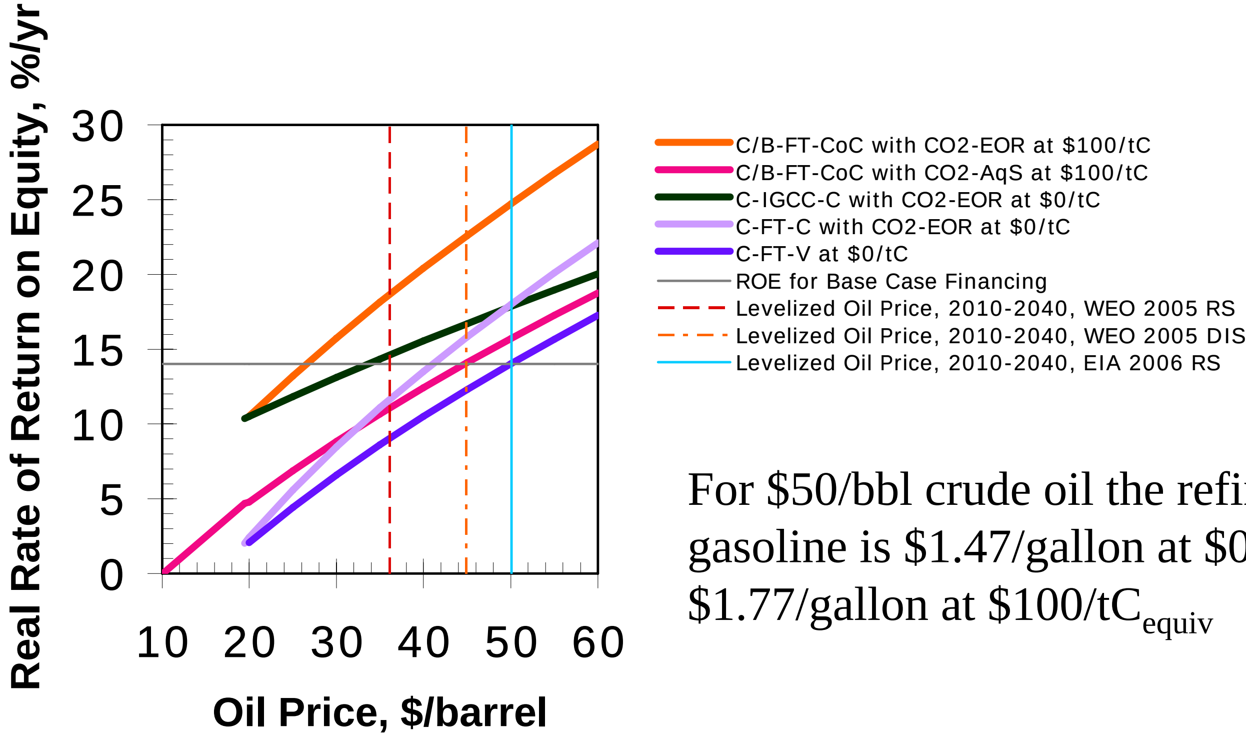
- Advanced Resources International Estimate of US EOR potential for US DOE—10 basin study of 1584 reservoirs :
  - 47 x 10^9 barrels (*economic potential*, *current technology*)
  - 89 x 10^9 barrels (*technical potential*, *current technology*)
  - 129 x 10^9 barrels (*technical potential*, *advanced technology*)
- Exploitable CO_2-EOR potential up to 3 x 10^6 barrels/day by 2020
- Perspective:
  - 0.216 x 10^6 barrels per day CO_2-EOR in 2000
  - US domestic oil production, 2002: 5.74 x 10^6 B/D
  - US proved oil reserves as of 1 January 2003: 24 x 10^9 barrels
- Challenge and opportunities for gasification-based energy:
  - CO_2-EOR expansion is CO_2 supply-constrained
  - FTL from coal or coal/biomass ➔ abundant, low-cost CO_2
  - ~ 4 barrels crude oil via EOR per barrel F-T liquids
  - C-IGCC-C also offers promise in providing low-cost CO_2 for EOR

ECONOMICS OF F-T POLYGENERATION

System	C-FT-V		C-FT-C		C-FT-CoC		C/B-FT-CoC	
F-T liquids output	14,000 barrels of gasoline equivalent/day (1030 MW)							
Electricity coproduct	461 MW_e		430 MW_e		428 MW_e		460 MW_e	
GHG emission rate relative to HC fuels from crude oil	1.80		1.08		1.03		0.21	
GHG emissions price, $/tC	0	100	0	100	0	100	0	100
Electricity price, ¢/kWh	4.7	6.9	4.7	6.9	4.7	6.9	4.7	6.9
Breakeven crude oil price, $/barrel								
CO_2-AqS	50	61	66	55	59	48	68	45
CO_2-EOR	-	-	42	40	40	38	42	37

Base Case Financing: levelized annual capital charge rate = 15%/y
(*55% debt and 45% equity,*
4.4%/y and 14.0%/y real rates of return on debt and equity, respectively)

PROFITABILITY OF ALTERNATIVE CAPTURE OPTIONS + CO_2–EOR or CO_2-AqS vs OIL PRICE



For $50/bbl crude oil the refinery-gate cost of gasoline is $1.47/gallon at $0/tC$_{equiv}$ and $1.77/gallon at $100/tC$_{equiv}$

- CO_2-EOR at $0/tC$_{equiv}$: C-IGCC-C (*C-FT-C*) is more profitable for oil prices less (*greater*) than $50/bbl
- C/B-FT-C at $100/tC$_{equiv}$:$CO_2$-EOR very profitable (*very powerful incentive to commercialize needed biomass gasification technologies ASAP*); CO_2-AqE has respectable profitability
- All options have respectable profitability at $50/bbl = levelized oil price 2010-2040 for Reference Scenario in EIA, *AEO 2006*
- Zero risk of "foreclosure" if oil price collapses (*positive ROE even for ultra-low oil prices*)

THOUGHT EXPERIMENT #2 FOR US

- Use coal IGCC and FT polygeneration CO_2 to support 3.0×10^6 barrels/day crude oil production via EOR by 2020
  - CO_2 from 50/50 mix of C-FT-C and C-IGCC-C through 2015
    - 11 C-IGCC-C plants (*360 MW_e each*)
    - 5 C-FT-C plants (*each producing 14,000 B/D FTL + 430 MW_e*)
  - All new projects C/B-FT-CoC thereafter
    - 36 C/B-FT-CoC plants (*each producing 14,000 B/D FTL + 460 MW_e*)
- <u>Implications</u>:
  - 590,000 B/D of low GHG-emitting FTL by 2020
    - Average FTL GHG emission rate = 31% of that for oil-derived HC fuels displaced
  - 23 GW_e decarbonized (*2/3 of projected coal capacity expansion*, *2011-2020*)
    - Ave GHG emission rate = 11% of projected average for coal power plants in 2020
  - FTL + EOR in 2020 ≡ 65% of 2020 domestic crude production
    - Reduction in 2020 oil import bill = $\$67 \times 10^9$/year (*25% of projected import bill*)
    - Required investment in gasification energy = $\$76 \times 10^9$
  - Net US coal consumption in 2020 up 3.5%
  - Biomass required ≡ 27% of currently available crop residues
  - CO_2 storage rate in 2020 = 231×10^6 tonnes CO_2/year

ARI (2005) ASSESSMENT OF CO_2-EOR POTENTIAL

Basin/Area	# of Large Reservoirs		Billions of Barrels of Oil			
			Contained Oil		CO2-EOR Potential	
	Assessed	EOR Favorable	OOIP	ROIP	Technical	Economic
Alaska	34	32	67.3	45.0	12.4	7.7
California	**172**	**88**	**88.3**	**57.3**	**5.2**	**3.3**
Gulf Coast	242	158	44.7	27.8	6.9	2.3
Mid-Continent	222	97	89.6	65.6	11.8	6.2
North Central	154	72	17.8	11.5	1.5	0.6
Permian	207	182	95.4	61.7	20.8	10.8
Rockies	162	92	33.6	22.6	4.2	2.4
Texas, East/Central	199	161	108.0	72.6	17.3	8.6
Williston	93	54	13.2	9.4	2.7	0.5
Lousiana offshore	99	99	28.1	15.7	5.9	4.4
Total	1584	1035	582	389	88.7	46.8

California petcoke production (21,500 t/d) could support 4 C/B-FT-CoC poly-generation units that in turn could support 0.25 MMB/D of CO_2-EOR for ~ 35 years

CONCLUSIONS

- At \$100/tCequiv and \$45-50/bbl oil the climate and supply security issues associated with transportation fuels and electricity seem to be soluble on the supply side with commercially ready (*coal*) and near-commercial (*biomass*) technologies
- California could lead the way by exploiting its significant CO_2-EOR potential and supplies of petcoke (*which can provide gasification energy at lower cost than coal*)
- Commercial success with super-clean designer synfuels could help bring about shift to more fuel-efficient vehicles…e.g., compression-ignition-engine hybrids
- More R&D/demonstrations but no radical technological innovations are needed
- Major technical uncertainty = "gigascale" viability of CO_2 storage—need much more "megascale" CO_2 storage experience…ASAP
  - All near term CO_2-EOR projects should become scientific laboratories…like Weyburn
  - Also megascale CO_2-AqS demos are needed and should be host to wide range of scientific investigations
- Climate mitigation policy needed…but extensive early CCS action via CO_2-EOR should be undertaken without waiting for such a policy
- Main obstacles appear to be institutional/cultural challenges:
  - Overcoming widespread ill feelings about coal synfuels—costly synfuels failures of late 1970s-early 1980s
  - Can oil, coal, and biomass industries become strategic energy production partners?
  - Coalition-building for proposed strategy—across multiple industries


BIG
COAL
GRO
MOR
CARS
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US
BIG
OIL